International Journal of Trend in Scientific Research and Development (IJTSRD)
Volume 9 Issue 4, Jul-Aug 2025 Available Online: www.ijtsrd.com e-ISSN: 2456 – 6470

# Modeling and Analysis for the Enhancement of High Voltage AC Transmission System Using Static Var Compensator

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## ABSTRACT

This paper focuses on enhancing the performance and stability of high voltage AC transmission systems by implementing a Static Var Compensator (SVC). In modern power networks, voltage instability and reactive power imbalance are critical challenges, especially under dynamic loading conditions and long-distance power transfer. The SVC, as a part of Flexible AC Transmission Systems (FACTS), provides dynamic reactive power compensation, which helps maintain voltage profiles, reduce transmission losses, and increase power transfer capability. In this study, a high voltage transmission system is modeled and analyzed using MATLAB/Simulink to observe the impact of SVC. Simulation results demonstrate significant improvements in voltage regulation, power losses, and transmission line capacity when the SVC is applied. This research validates the effectiveness of SVC in optimizing system performance and ensuring reliable power delivery in high voltage networks.

***KEYWORDS:*** *Static Var Compensator (SVC); High Voltage AC Transmission; Reactive Power Compensation; Power Transfer Capacity.*

***How to cite this paper:*** May Nwe Yee Tun | Soe Soe Ei Aung "Modeling and Analysis for the Enhancement of High Voltage AC Transmission System Using Static Var Compensator" Published in International Journal of Trend in Scientific Research and Development (ijtsrd), ISSN: 2456-6470, Volume-9 | Issue-4, August 2025, pp.980-987, URL: www.ijtsrd.com/papers/ijtsrd97352.pdf

IJTSRD97352

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## I. INTRODUCTION

High voltage alternating current (HVAC) transmission systems are the backbone of electrical power networks, enabling long-distance power delivery from generation sites to load centers. However, these systems are often subjected to challenges such as voltage instability, power losses, and reduced transfer capacity, particularly during peak loads or fault conditions. One of the primary causes of such issues is the imbalance in reactive power, which directly affects voltage stability and system reliability.

To address these challenges, Flexible AC Transmission Systems (FACTS) have been developed, with the Static Var Compensator (SVC) being one of the most widely used devices. An SVC provides rapid and continuous reactive power compensation, thus improving voltage control and enhancing system stability. By adjusting the reactive power flow in real time, the SVC mitigates voltage drops, supports load demands, and enhances the power transfer capability of transmission lines.

This paper investigates the modeling and analysis for the enhancement of an HVAC transmission system integrated with an SVC. Using MATLAB/Simulink, the performance of the system is analyzed under maximum load operating conditions. The goal is to demonstrate the effectiveness of SVC in improving voltage profiles, minimizing losses, and boosting the stability and efficiency of high voltage transmission systems.

## II. High Voltage AC Transmission System

High Voltage Alternating Current (HVAC) transmission systems are essential components of modern power grids. They are used to transfer electric power efficiently over long distances from generating stations to load centers. Due to the large amounts of power involved and the geographical distances between generation and consumption, high voltage levels are employed to reduce current and thereby minimize power losses and voltage drops.

The fundamental objectives of an HVAC transmission system are:

1. To transmit power with minimal losses,

2. To maintain voltage within acceptable limits at all points in the system,
3. To maximize the power transfer capacity without compromising system stability.

HVAC systems are characterized by three key performance aspects, described below:

### A. Voltage Regulation

Voltage regulation is a measure of how well the transmission system maintains a constant voltage at the receiving end under varying load conditions. In an ideal system, the receiving end voltage should remain the same regardless of the load, but practical systems experience voltage drops due to line impedance (resistance and inductive reactance). Excessive voltage drops can lead to inefficient equipment operation, power quality issues, or even system instability.

Voltage regulation is expressed as a percentage difference between no-load and full-load receiving end voltages. The voltage drop at the receiving end should not exceed 5% of the rated voltage. Systems with poor voltage regulation are often supported by reactive power compensating devices like SVCs (Static Var Compensators) and capacitor banks, which dynamically manage the reactive power flow.

### B. Power Losses

Power losses in HVAC transmission systems primarily occur due to the resistance of transmission conductors. These are known as $I^2R$ losses, where current squared is multiplied by the resistance of the line. Higher transmission voltages allow for lower current in the same power level, which significantly reduce these losses.

Additionally, there are reactive power losses, which affect voltage profiles and reduce the effective power that can be delivered to the load. Minimizing power losses is critical for system efficiency, operational cost reduction, and environmental sustainability. Losses can be reduced by increasing the transmission voltage level, improving conductor material and configuration and applying reactive power compensation.

### C. Power Transfer Capacity

Line capacity refers to the maximum amount of electric power, including both real power (MW) and apparent power (MVA), that a transmission line can safely and reliably transmit without exceeding operational or physical limits. It is one of the most critical factors in transmission system design, operation, and planning.

There are three transmission line capacity. They are

1. Thermal limit (based on MVA or current),
2. Voltage stability limit (reactive power and voltage drop),
3. Angle stability limit (based on the power angle δ).

In this research, transmission line capacity such as thermal limit (based on MVA) is used.

## III. Application of SVC for Transmission System Improvement

SVC is applied in power system to stabilize the voltages in weak power systems; reduce power losses in transmission lines; increase the transmission capacity to reduce, defer, or eliminate the need for new lines; contribute to power and voltage oscillations damping and enhance voltage and stability control.

### 1. Voltage Profile Improvement:

SVC maintains the voltage at desired levels by absorbing or injecting reactive power at strategic locations.

### 2. Loss Reduction:

By improving voltage levels and power factor, SVC minimizes both real and reactive power losses in transmission lines.

### 3. Increased Power Transfer Capability:

SVC enhances the load ability of transmission lines by improving voltage stability and reducing overloading conditions.

## IV. Modeling and Simulation for 230 kV Upper Myanmar Transmission System

This paper implemented modeling and simulation for 230 kV double circuit AC transmission line in Upper Myanmar. The single line diagram of the selected transmission system is shown in Figure 1.

In this research, there are two hydro power generation stations are included, Shweli Station (600 MW) and Yeywa Station (790MW).

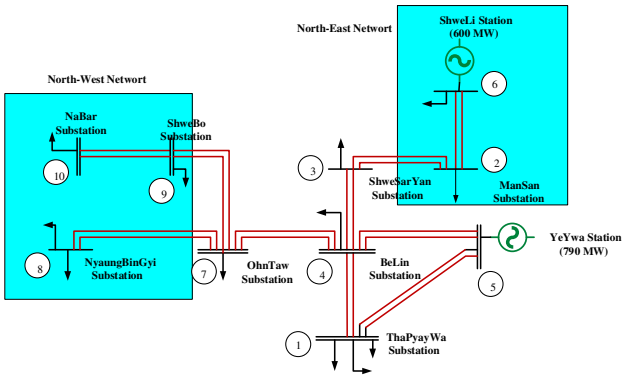


**Figure. 1: Single Line Diagram of 230 kV Upper Myanmar Transmission System**

And, the improvement of high voltage AC transmission system is analyzed at ten high voltage double circuit transmission lines. Specification of double circuit transmission lines, voltage level, line length and current limit are described in Table I.

**Table I. Specification of Double Circuit Transmission Lines**

| Substation | | Voltage Level (kV) | Line Length (km) | I-limit (A) |
|---|---|---|---|---|
| *From* | *To* | | | |
| Shweli | Mansan | 230 | 95.9 | 1425 |
| Mansan | Shwesaryan | 230 | 194.0 | 975 |
| Shwesaryan | Belin | 230 | 27.6 | 1770 |
| Yeywa | Belin | 230 | 39.1 | 1770 |
| Yeywa | Thapyaywa | 230 | 112.2 | 1593 |
| Thapyaywa | Belin | 230 | 87.9 | 1682 |
| Belin | Ohntaw | 230 | 53.6 | 1500 |
| Ohntaw | Nyaungbingyi | 230 | 87.6 | 1425 |
| Ohntaw | Shwebo | 230 | 83.6 | 1756 |
| Shwebo | Nabar | 230 | 204.3 | 1054 |

The Simulink model is constructed according to single line diagram that is shown in figure and the data described above. The Simulink model for the case study is shown in Figure 2.

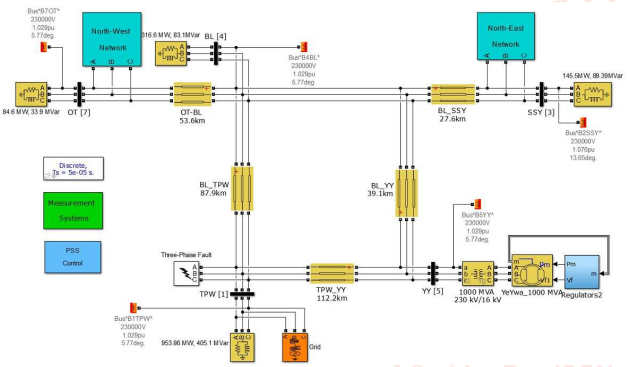


**Figure. 2: Simulink Model for Without SVC**

To observe the improvement of high voltage AC transmission system, the simulations are carried out for maximum load condition. The load data for the case study under maximum loading conditions is summarized in the Table II, detailing the active and reactive power demands at each bus.

**Table II. Loads Data of Case Study (Maximum Condition)**

| Bus No | Substation | Active Power (MW) | Reactive Power (MVAr) |
|---|---|---|---|
| 1 | TPW | 953.86 | 405.1 |
| 2 | MS | 48.1 | 14.9 |
| 3 | SSY | 145.5 | 89.39 |
| 4 | BL | 316.6 | 83.1 |
| 5 | YY | 0 | 0 |
| 6 | SL | 0 | 0 |
| 7 | OT | 84.6 | 33.9 |
| 8 | NBG | 236.6 | 164.8 |
| 9 | SB | 21.19 | 9.4 |
| 10 | NB | 90.64 | 25.24 |

The total load demands of the system are 1897.09 MW and 825.83 MVAr. After modeling of the existing system without SVC, the simulations are carried out for normal condition with maximum load. Figure 3 and Figure 4 show the bus voltages profile at each bus.

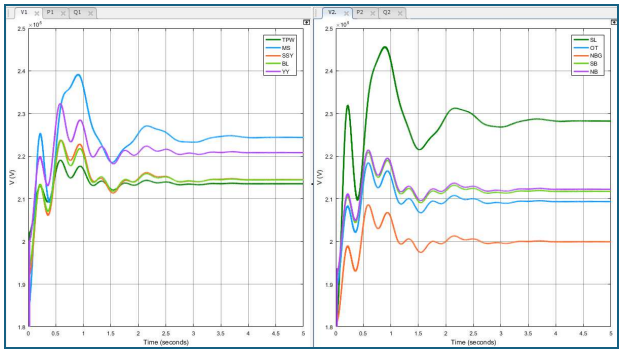

**Figure.3: Simulation Results of Bus Voltage Profile (without SVC)**

Among the buses 1, 3, 4, 7, 9 and 10, Bus 8 (Nyaungbingyi Substation) has the lowest voltage at 0.8691 p.u, which is below standard acceptable range of 0.95 p.u to1.05 p.u. This indicates a potential issue of voltage instability in that area of the network. In power system, low voltage typically results from inadequate reactive power, which is often seen in long transmission system or at buses with high demand and limited local generation. As a result, the poor voltage regulation at Bus 8 requires immediate corrective action, and Buses 7,9 and 10 also require voltage support to avoid further voltage deterioration. Long transmission lines and high reactive power demand cause voltage instability, necessitating dynamic compensation. The bus voltage condition without SVC of the existing transmission system is shown in Figure 4.

Figure 5 and Figure 6 show the active and reactive power at each bus without compensation with SVC.

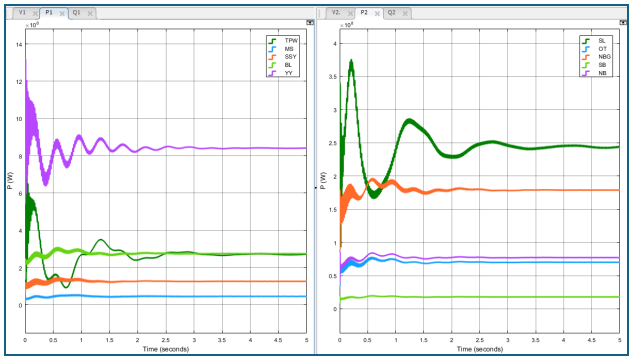

**Figure.5: Simulation Results of Active Power at each bus (without SVC)**

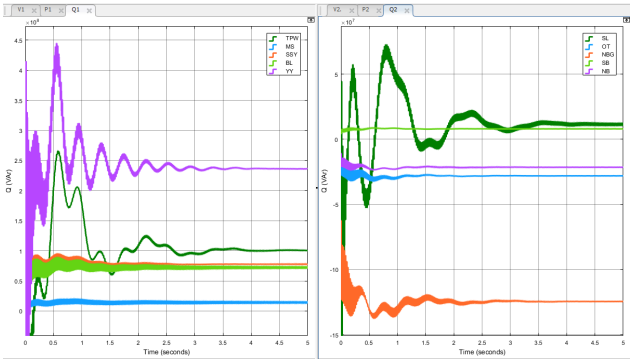

**Figure. 6: Simulation Results of Reactive Power at each bus (without SVC)**

Active and reactive power flow under existing system are described in Figure 7. Active power flows indicate heavy loading on lines like 4-5 (601.8 MW) and 4-7 (444.1 MW), contributing to losses. Unoptimized power flow leads to inefficiencies, especially in lines with high impedance or length (e.g., Shwebo-Nabar: 204 km).

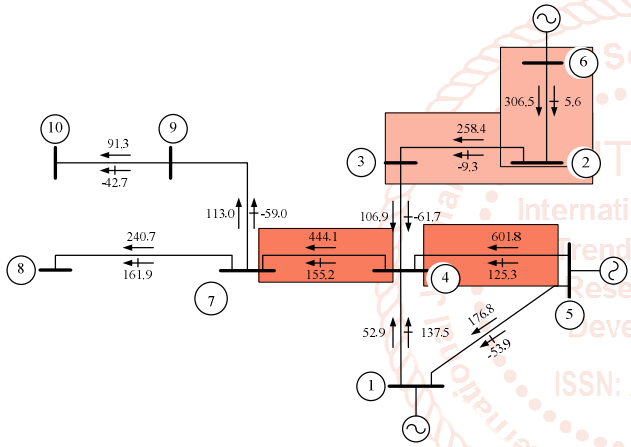


**Figure.7: Active and Reactive Power Flow (without SVC)**

Reactive power deficits are pronounced at Bus 8 (164.8 MVAr demand) and Bus 1 (405.1 MVAr), exceeding local generation capacity. Reactive power imbalance exacerbates voltage drops, validating the need for SVC to inject/absorb VARs dynamically. The Bus 4 to Bus 5 line operates at 88.9% of its thermal limit (626.8 MVA out of 705.1 MVA), making it susceptible to overload under contingency conditions or increased demand. The high reactive power flow on Line 7 to 8 (161.9 MVAr) is associated with low voltages at Bus 7 (0.9104 p.u) and Bus 8 (0.8691 p.u), confirming a reactive power deficiency in this area.

And then, power transfer capacity is carried out from the maximum apparent power and limited apparent power. The resulted power transfer capacity of each transmission line is organized in Figure 8.

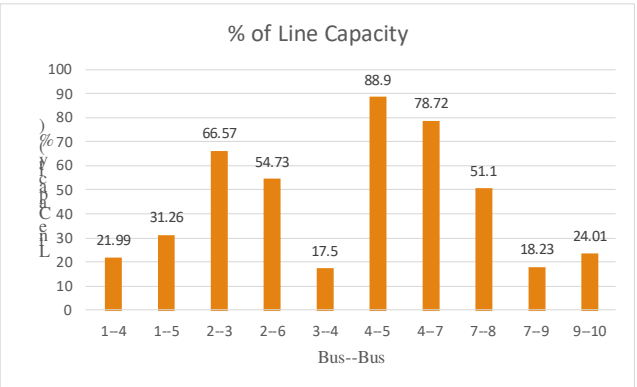


**Figure. 8: Power Transfer Capacity Without SVC**

The Bus 4 to Bus 5 operates at 88.9 % of its thermal limit (626.8 MVA out of 705.1 MVA), making it susceptible to overload under contingency conditions or increased demand. Thus, the Bus 4 to Bus 5 is particularly weak to overload during peak demand or generation shifts. Overall, most transmission lines operate within safe margins (<90% of capacity), maintaining system reliability under normal conditions. However, voltage instability remains a concern in the Bus 7, Bus 8 and Bus 9 corridor, primarily driven by excessive reactive power demand.

## V. Improvement of System Using SVC

For the purpose of analysis and simulation, SVC is typically modeled as a variable reactive power source connected in shunt to the transmission system.

### A. Location and Sizing of SVC

In compensation, the most important one is the sizing and allocation of compensation devices in the system. To determine the sizing and allocation of SVC, the steady state load flow programme is executed with MATLAB. Newton-Raphson method is employed for load flow analysis. From the simulation results, the location of SVC is chosen at Bus 7 (Ohntaw Substation). The required input data to calculate the parameter of SVC is shown in Table III.

**Table III. Input Data for SVC Design**

| Parameter | Symbol | Rating | Unit |
|---|---|---|---|
| Voltage at SVC connection point | V | 11 | kV |
| System frequency | f | 50 | Hz |
| Active power of load at selected bus | $P_{load}$ | 444.1 | MW |
| Reactive power of load at selected bus | $Q_{load}$ | 155.2 | MVAr |
| Short circuit level of the bus | $S_{sc}$ | 3000 | MVA |
| Resistance to reactance ratio of impedance at selected bus | k | 0.125 | - |

Therefore, the following equations (1) to (5) are used to calculate the parameter of SVC. Equation (1) is used to calculate the reactive power produced by SVC.

$$Q_{SVC} = Q_{load} + \frac{P_{Load}^2}{2 \times S_{sc}} + (k\, P_{Load}) \quad (1)$$

Where: $Q_{SVC}$ = Minimum rating of SVC, $P_{load}$ = Active power of load at selected bus, $Q_{load}$ = Reactive power of load at selected bus, $S_{SC}$= Short circuit level of the bus and k = Resistance to reactance ratio of the impedance at selected bus.

And then, the inductive reactance and inductance of TCR is calculated by using equation (2) and (3). Next, the capacitive reactance and the capacitance of TSC are calculated by using equation (4) and (5).

$$X_{TCR} = \frac{V^2}{Q_{TCR}/3} \quad (2)$$

$$L = \frac{X_{TCR}}{2 \times \pi \times f} \quad (3)$$

$$X_{TSC} = \frac{V^2}{Q_{TSC}/3} \quad (4)$$

$$C = \frac{1}{2 \times \pi \times f \times X_{TSC}} \quad (5)$$

By inserting the input data into the above equations, the design of SVC is calculated. The output data of SVC design is tabulated in Table III.

**Table IV. Output Data for SVC Design**

| Parameter | Symbol | Rating | Unit |
|---|---|---|---|
| Capacitance for TSC | C | $7.015 \times 10^{-4}$ | F/ph |
| Reactance for TSC | $X_{TSC}$ | 4.5375 | Ω/ph |
| Inductance for TCR | L | 0.0144 | H/ph |
| Reactance for TCR | $X_{TCR}$ | 4.5357 | Ω/ph |
| Required Reactive Power Compensation | $Q_{TCS}$, $Q_{TCR}$ | 80 | MVAr |
| Overall Capacity of SVC | $Q_{SVC}$ | 240 | MVAr |

## B. Modeling and Simulation with SVC

The operation of an SVC involves modulating reactive power using a combination of thyristor-controlled reactor (TCR) and thyristor-switched capacitors (TSCs). TCR includes a fixed inductor (with inductance L) connected in series with bidirectional thyristor valves, allowing variable inductive reactive power. TSC consists of a capacitor, bidirectional thyristor valves, and a small inductor to limit surge currents, enabling discrete steps of capacitive reactive power. In this paper, TSC-TCR configuration is used consisting of three numbers of TSC and one number of TCR since it is the commonly used configuration and suitable for SVC rating of 240 MVAr. With this arrangement, the range of SVC is combination of 80 MVAr TCR and 240 MVAr TSC (80 MVAr- 3 numbers). Modeling of SVC for the enhancement of high voltage AC transmission system is shown in Figure 9. The Simulink model of transmission line compensated with SVC is shown in Figure 10.

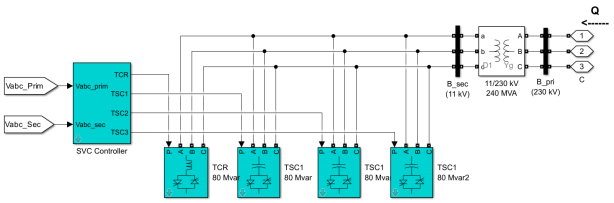


**Figure. 9: Modeling for SVC**

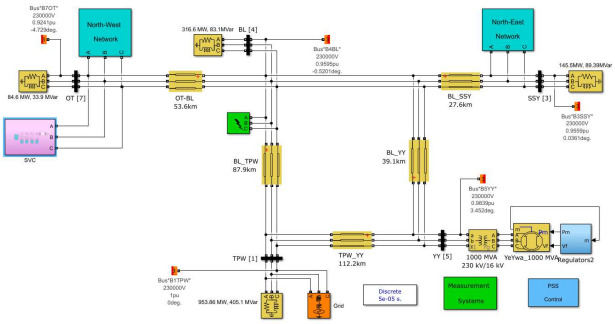


**Figure. 10: Simulink Model of Transmission Line Compensated with SVC**

Figure 11 and Figure 12 show the bus voltages profile at each bus compensated with SVC.

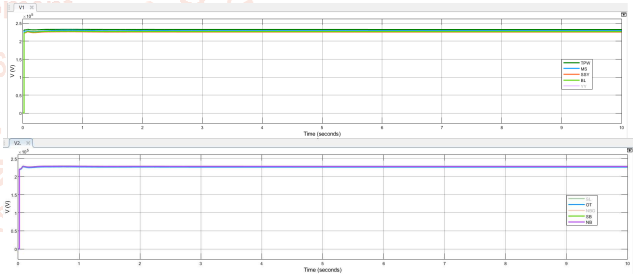


**Figure. 11: Simulation Results of Bus Voltage Profile (Compensated with SVC)**

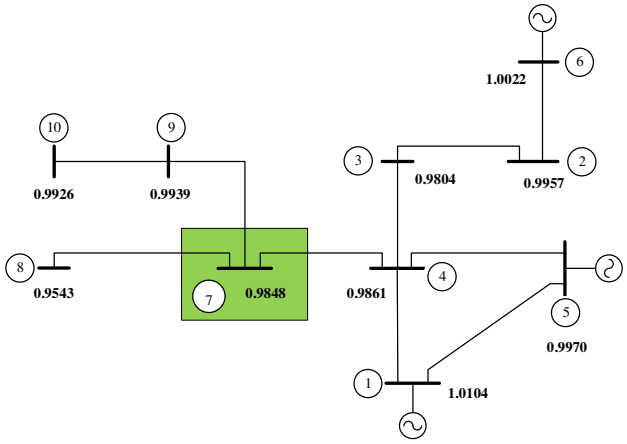


**Figure. 12: Bus Voltage Condition with SVC**

Active and reactive power flow in the lines compensated with SVC are described in Figure 13.

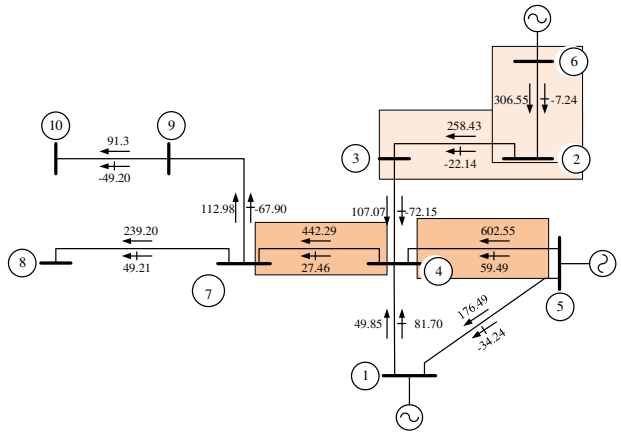


**Figure. 13: Line Flow Compensated with SVC**

## VI. Analysis for Improvement with SVC

The bus voltage data presented in Table V clearly demonstrates the significant impact of implementing a Static Var Compensator (SVC) on system voltage stability. Before compensation, several buses exhibited voltage levels well below the nominal operating voltage of 230 kV. For instance, Bus 8 (Nyaungbingyi) recorded the lowest voltage at 199.9 kV, indicating a potentially critical undervoltage condition that could compromise system reliability and equipment performance. After the integration of the SVC, Bus 8 voltage increased substantially to 219.5 kV, reflecting the effective injection of reactive power by the SVC to stabilize voltage levels.

**Table V. Power System Voltage Profile (Without and With SVC)**

| Bus No. | Bus Voltage without SVC (kV) | Bus Voltage with SVC (kV) |
|---|---|---|
| 1. | 213.5 | 232.4 |
| 2. | 224.4 | 229 |
| 3. | 214.5 | 225.5 |
| 4. | 214.4 | 226.8 |
| 5. | 220.8 | 229.3 |
| 6. | 228.2 | 230.5 |
| 7. | 209.4 | 226.5 |
| 8. | 199.9 | 219.5 |
| 9. | 211.7 | 228.6 |
| 10. | 212.2 | 228.3 |

Overall, each of the ten buses experienced a voltage increase with the application of the SVC. The most notable improvements were observed at Bus 1 (from 213.5 kV to 232.4 kV), Bus 7 (from 209.4 kV to 226.5 kV), and Bus 10 (from 212.2 kV to 228.3 kV). These increases demonstrate the SVC's capacity to regulate voltage by supplying or absorbing reactive power as needed, especially during periods of voltage depression.

Even buses that were already operating near nominal levels, such as Bus 6 (from 228.2 kV to 230.5 kV), saw improvements. This reflects the SVC's role not only in correcting low voltages but also in enhancing voltage uniformity across the system.

**Table VI. Power Transfer Capacity (Without and With SVC)**

| Bus (send) | Bus (receive) | Line Capacity without SVC (%) | Line Capacity with SVC (%) | Line Capacity Drop (%) |
|---|---|---|---|---|
| 1 | 4 | 21.99 | 14.28 | 7.71 |
| 1 | 5 | 31.26 | 28.33 | 2.93 |
| 2 | 3 | 66.57 | 66.78 | -0.21 |
| 2 | 6 | 54.73 | 54.01 | 0.72 |
| 3 | 4 | 17.5 | 18.31 | -0.81 |
| 4 | 5 | 88.9 | 85.87 | 3.03 |
| 4 | 7 | 78.72 | 74.15 | 4.57 |
| 7 | 8 | 51.1 | 43.02 | 8.08 |
| 7 | 9 | 18.23 | 18.84 | -0.61 |
| 9 | 10 | 24.01 | 24.70 | -0.69 |

The Table VI presents a comparative analysis of transmission line capacity utilization (in percentage) between sending and receiving buses, both without and with the implementation of a Static Var Compensator (SVC). The data clearly illustrates that SVC integration generally leads to reduced line loading, particularly on heavily loaded and long-distance transmission lines.

The most significant reduction is observed on Line 1→4, where the capacity drops from 21.99% to 14.28%, indicating a notable relief in power flow due to voltage and reactive power support from the SVC.

Line 4→5 and 4→7, which originally operate at 88.9% and 78.72% capacity respectively, also show improved performance with SVC, reducing to 85.87% and 74.15%. These lines are among the most heavily loaded, and the SVC helps offload stress and improve system security.

Therefore, the majority of the lines, such as 1→4, 1→5, 2→6, 4→5, 4→7, and 7→8, exhibit a positive line capacity drop, indicating a decrease in power flow loading. For instance, line 1→4 shows the most significant improvement with a drop of 7.71%, and line 7→8 follows closely with an 8.08% drop. These results demonstrate the SVC's capacity to relieve heavily loaded lines, reduce transmission stress, and enhance overall power flow efficiency. The reductions suggest that the SVC provides effective voltage regulation and reactive power compensation, redistributing power flows across the system.

In a few cases, like Line 2→3 and 3→4, there is a slight increase in line loading (e.g., from 66.57% to 66.78%, and 17.5% to 18.31%, respectively). This is likely due to power rerouting effects, where the

SVC's presence shifts flow paths to more balanced routes.

The changes in Lines 9→10 and 7→9 are minimal, indicating that SVC has localized impact, with greater effects near its installation point or at buses experiencing critical voltage/reactive power conditions.

The overall behavior confirms that the SVC improves system operability by reducing critical line congestion, allowing the redistribution of power flow, and enabling better use of the existing transmission infrastructure. While some localized increases in line loading occur, they reflect the improved stability and dynamic response of the network rather than a fault or overload condition.

**Table VII. Transmission Line Losses and Efficiency (Without and With SVC)**

| Parameter | Without SVC | With SVC |
|---|---|---|
| Total Generation | 1932.574 MW | 1929.725 MW |
| Total PQ Load | 1897.089 MW | 1897.090 MW |
| Total Losses | 35.48 MW | 32.635 MW |
| Efficiency | 98.164 % | 98.309 % |
| Percent Losses | 1.836 % | 1.491 % |

The Table VII illustrates key power system parameters such as generation efficiency and system losses before and after the integration of a Static Var Compensator (SVC).

One of the most notable improvements is observed in the total transmission losses, which decrease from 35.48 MW to 32.635 MW after the SVC is introduced. This 2.845 MW reduction in losses represents improved voltage stability and reduced reactive power circulation, both of which contribute to lower power dissipation along transmission lines. As a result, more generated power reaches the actual load centers.

This reduction in losses is also reflected in the percent losses, which drop from 1.836% to 1.491%, confirming that the system becomes more energy-efficient with SVC support.

Additionally, overall efficiency improves from 98.164% to 98.309%, indicating that a greater portion of generated power is being effectively utilized. This efficiency gain aligns with the SVC's role in reactive power compensation, which reduces voltage drops and optimizes real power delivery across the system.

It is important to highlight that the total generation decreases slightly from 1932.574 MW to 1929.725 MW, while the total active and reactive load remains virtually constant. This indicates that the power system is able to meet the same load requirement with reduced generation, due to the efficiency improvements provided by the SVC. Supplying the same demand with less generated power reflects both economic savings and technical advantages through reduced internal losses.

According to these results, the SVC has a significant impact on improving overall system efficiency, reducing energy losses, and ensuring reliable power delivery in high-voltage AC transmission networks.

## VII. Conclusion

In conclusion, the integration of the Static Var Compensator into the high-voltage AC transmission network resulted in improved voltage profiles at all observed buses. The system exhibited enhanced voltage stability, reduced risks of undervoltage conditions, and better preparedness to handle dynamic load variations. These outcomes confirm that the SVC is an effective solution for reactive power compensation and voltage regulation in modern power systems. From this research, the SVC can operate not only mitigating low voltage conditions but also improving voltage consistency throughout the system.

From the analysis of transmission line capacities before and after the implementation of the Static Var Compensator (SVC) clearly demonstrates the SVC's effectiveness in enhancing power system performance. A majority of the transmission lines experienced a reduction in line capacity usage, confirming the SVC's role in relieving congestion, improving voltage profiles, and supporting reactive power demands. This reduction in loading contributes to greater system stability, lower transmission losses, and improved voltage regulation.

In contrast, a few lines exhibited a slight increase in capacity usage. However, this is not a drawback but a reflection of optimized power redistribution, as the SVC enables a more balanced flow of electricity across the network. These increased line utilizations result from improved conditions in the system, allowing previously underutilized lines to contribute more effectively to overall power delivery.

Overall, the analysis confirms that implementing an SVC in a high-voltage AC transmission system enhances operational flexibility, alleviates stress on heavily loaded lines, and boosts the reliability and efficiency of power transmission. This supports the SVC as a valuable solution for modern power system enhancement and stability improvement.

**Acknowledgment**

I would like to specifically thank Reactor, Yangon Technological University, for giving the permission to submit the paper.

I would like to thank my teachers from department of Electrical Power Engineering, YTU, for their helpful

and valuable suggestions and guidance in the preparation of the paper.

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